GLACIER MONITORING USING TIME-LAPSE IMAGERY
THE CASE STUDY OF THE PLANPINCIEUX GLACIER

NICCOLÒ DEMATTEIS

NATIONAL RESEARCH COUNCIL OF ITALY
RESEARCH INSTITUTE OF THE GEO-HYDROLOGICAL PROTECTION
GEOHAZARD MONITORING GROUP
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Digital Image Correlation (DIC)

DIC developed in the 80s for laboratory experiments.

In Earth sciences, DIC was applied mostly on aerospace images during the 90s.

The first study of terrestrial DIC on glacier was in 2000 to measure the surface velocity of the Godely Glacier (NZ)\(^1\)

However, continuous DIC monitoring plans are rare.
DIC - FUNDAMENTALS

The principle of DIC is to search for the displacement of an image tile between two acquisitions of the same scene.
DIC - FUNDAMENTALS

THIS IS DONE WITH THE CALCULUS OF THE SPATIAL CROSS-CORRELATION (\textit{CC})

\textit{CC} IS A SIMILARITY INDEX CALCULATED BETWEEN THE REFERENCE TEMPLATE AND MULTIPLE CANDIDATES OF SEARCHING TEMPLATES.

THE POSITION WHERE THE BEST SIMILARITY IS FOUND CORRESPONDS TO THE DISPLACEMENT OF THE REFERENCE TEMPLATES.
DIC ACCURACY AND PRECISION

SUBPIXEL SENSITIVITY

ADOPTING AN INTERPOLATION OF THE CROSS-CORRELATION MATRIX IT IS POSSIBLE TO OBTAIN A SUB-PIXEL MEASUREMENT

UNCERTAINTY

TYPICAL UNCERTAINTY IN GLACIOLOGICAL SURVEYS IS 0.5 – 1 PX
DIC - MONITORING APPLICATION

Typical DIC application for glacier monitoring is to acquire an image sequence using a DSLR camera. DIC processing produces daily results.
DIC - PROCESSING

Glacier monitoring using time-lapse imagery
Glacier monitoring using time-lapse imagery

**IMAGE SELECTION**

FUNDAMENTAL TO OBTAIN HIGH-QUALITY RESULTS

MOSTLY DONE MANUALLY → HUMAN EFFORT REQUIRED

- **SHADOWS**
- **SIMILAR ILLUMINATION**
- **DIFFUSE ILLUMINATION**
- **NO VISIBILITY**
IMAGE PROCESSING

DIC WORKS WITH MONOCHROMATIC IMAGES

RGB to BW
COREGISTRATION

COMPENSATE IMAGE TRANSLATION USING STABLE AREA AS REFERENCE
CALCULATING SURFACE DISPLACEMENTS

SLIDING WINDOW WHERE TO CALCULATE CROSS-CORRELATION

RAW RESULT

RESULT REFINEMENT
DIC - OUTPUT

MAPS OF DISPLACEMENT COMPONENTS ORTHOGONAL TO THE LINE OF SIGHT

VERTICAL COMPONENT

HORIZONTAL COMPONENT

**METRIC CONVERSION**

1 px = 2D \( \tan \left( \frac{S}{2f} \right) \)

IN THE PLANPINCIEUX GLACIER

1 PX = 5.5 CM
DIC - OUTPUT

RESULTS REPRESENTATION IN THE REAL-WORLD COORDINATES ALLOWS COMPARISON AND COUPLING WITH OTHER MONITORING SYSTEMS

ORTHORECTIFICATION

GEOREFERENCING
# DIC: A VALUABLE TOOL FOR GLACIER MONITORING

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<td>2D spatially-distributed results</td>
<td>Impossible during night and bad weather</td>
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<td>Remote sensing</td>
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<td>Low cost and portable hardware</td>
<td>Manual image selection</td>
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<td>Observation of complex geometries</td>
<td>No 3D information</td>
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<td>Simple processing and result interpretation</td>
<td>Low sensibility of the measurement (irrelevant for fast glaciers)</td>
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CASE STUDY: PLANPINCIEUX GLACIER

VIEW FROM THE MONITORING STATION
PLANPINCIEUX GLACIER

GLACIER ELEVATION 2500-3500 M

ACCUMULATION AREA COMPOSED OF TWO CIRQUES

ABLATION AREA COMPOSED OF TWO LOBES IN TEMPERATE THERMAL REGIME

MONTITAZ LOBE ~30° STEEP WITH MANY Crevasses

GLACIER TERMINUS IS IN CORRESPONDENCE OF A MORPHOLOGICAL STEP THAT CAUSES FREQUENT CALVING
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GLACIER SHRINKAGE

IN 20 YEARS THE GLACIER RETREATED A FEW HUNDRED METERS
GLACIER SHRINKAGE

DEM OF DIFFERENCE

BETWEEN 2014 AND 2019, THE GLACIER THICKNESS DECREASED IN THE ABLATION AREA OF 12 M IN AVERAGE

VOLUME LOST

$2.5 \times 10^6$ m$^3$
PLANPINCIEUX GLACIER MONITORING

IN THE PAST SEVERE ICE BREAK-OFFS OCCURRED FROM THE MONTITAZ LOBE (IN OROGRAPHIC RIGHT)

THE PLANPINCIEUX GLACIER IS CONTINUOUSLY MONITORED SINCE 2013 WITH A TIME-LAPSE CAMERA WHICH MEASURES THE SURFACE DAILY VELOCITY

THE VISUAL INVESTIGATION OF THE IMAGES ALLOWS TO IDENTIFY THE BREAK-OFFS AND TO ANALYSE THE DEVELOPMENT OF INSTABILITY PROCESSES
PHOTOGRAPHIC MONITORING SYSTEM

TWO TIME-LAPSE CAMERAS WITH DIFFERENT OPTICAL LENGTH OBSERVE DIFFERENT GLACIER PORTIONS

SCHEDULED HOURLY ACQUISITION

REMOTE CONTROL WITH GPRS CONNECTION

AUTONOMOUS ENERGY SUPPLY WITH SOLAR PANELS

GLACIER DISTANCE IS 3800 M

HARDWARE GLOBAL COST APPROXIMATIVELY €10000
PHOTOGRAPHIC DATASET

MORE THAN 35000 IMAGES ACQUIRED IN 7 YEARS OF MONITORING ➔ HIGH TEMPORAL RESOLUTION
PRODUCTS OF THE MONITORING

MAPS OF DAILY MOTION

TIME SERIES OF VELOCITY

BREAK-OFF IDENTIFICATION

INSTABILITY PROCESSES

DIC: QUANTITATIVE

VISUAL ANALYSIS: QUALITATIVE

Glacier monitoring using time-lapse imagery
MONITORING RESULTS ARE AUTOMATICALLY COMMUNICATED EVERY DAY TO THE AUTHORITIES ON A RESTRICTED-ACCESS WEB PAGE

PERIODICAL BULLETINS DESCRIBE DETAILED INVESTIGATION OF THE GLACIER STATE AND REPORT THE VALIDATED RESULTS

PERIODICAL BULLETINS
KINEMATIC DOMAINS OF THE MONTITAZ LOBE

The surface velocity pattern is typically formed of 4 distinct kinematic domains.

The limits of the kinematic domains correspond to the crevasses which delimitate the morphological sectors.

The position of the crevasses indicate where the strongest tensile stresses act.

The portion below can become unstable and collapse.
A SERIES OF CREVASSES DEVELOPS EVERY YEAR APPROXIMATELY IN THE SAME POSITION

THE MONITAZ LOBE IS COMPOSED OF DISTINCT MORPHOLOGICAL SECTORS WHICH SHOW DIFFERENT BEHAVIOURS
CRISIS OF 2019 AND 2020

In 2019 and 2020, the two lower sectors merged → a larger volume became unstable (250000-500000 m³)

1 Oct 2019

16 Aug - 12 Oct 2019
TIME SERIES OF DAILY VELOCITY

EVERY YEAR A FEW SPEED-UP PERIODS OCCUR AND CULMINATE WITH LARGE BREAK-OFFS
BREAK-OFF DYNAMICS
THE CREVASSE DEVELOPMENT CAUSES THE TOPPLING OF THE ICE CHUNK
THE GLACIER SLIDING SUM WITH THE ROTATIONAL MOVEMENT AND YIELDS THE ACCELERATION
WHEN THE CREVASSE REACHES THE BEDROCK, THE ICE CHUNK COLLAPSES

MODIFIED FROM IKEN, 1977 [4]
VELOCITY vs VOLUME

IT HAS BEEN IDENTIFIED A MONOTONICAL RELATIONSHIP BETWEEN MAXIMUM GLACIER VELOCITY AND BREAK-OFF VOLUME DURING THE SPEED-UP PERIODS

A-PRIORI ESTIMATE OF THE VOLUME
BREAK-OFF VOLUME ESTIMATE

VOLUME IS ESTIMATED WITH 2D IMAGES ADOPTING ASSUMPTIONS OF ICE AND BEDROCK GEOMETRY

GOOD AGREEMENT WITH LIDAR DATA
BREAK-OFF IDENTIFICATION

PRE-EVENT

POST-EVENT

MAP OF CHANGE DETECTION AFTER THE BREAK-OFF
**BREAK-OFF CLASSIFICATION**

**Disaggregation:** Toppling of small fragments ($10^3 \text{ m}^3$) due to the motion beyond the bedrock cliff.

**Slab Failure:** Detachments of large ice lamella ($10^4$-$10^5 \text{ m}^3$) delimited by large crevasses often preceded by acceleration.

**Water Tunnelling:** Development and collapse of endoglacial tunnels.

**Break-off Volume for Every Break-off Process**

Glacier monitoring using time-lapse imagery
WHAT MAKES THE GLACIER MOVE?

**GRAVITY**

MORE RELEVANT DURING WINTER

**WINTER BEHAVIOUR**

DURING THE WARM SEASON, THE FRONTAL PORTION PARTIALLY DETACHES FROM THE MAIN GLACIER BODY

IN THE COLD SEASON, THE LOWER PART FREZEE AGAINST THE BEDROCK

THE GLACIER BODY MOVES FOR GRAVITY
WHAT MAKES THE GLACIER MOVE?

**LIQUID WATER**

**FACILITATES SLIDING**

- **ICE MELTING** $\rightarrow$ **HIGH TEMPERATURE CAN INCREASE GLACIER VELOCITY (?)**

- **WATER PERCOLATION** $\rightarrow$ **THE PRESENCE OF SNOW / THE ABSENCE OF Crevasses ON THE GLACIER SURFACE CAN REDUCE SLIDING (?)**

Glacier monitoring using time-lapse imagery
VELOCITY vs TEMPERATURE

SUMMER 2014 WAS MUCH COOLER THAN USUAL → IN 2014 SPEED-UP PERIODS DID NOT OCCUR

A CLEAR RELATION BETWEEN VELOCITY AND TEMPERATURE DOES NOT APPEAR
HYDRAULIC SYSTEM

WELL-DEVELOPED HYDRAULIC SYSTEM FACILITATES THE WATER DRAINAGE AND **DECREASES THE GLACIER SLIDING**

DIFFUSE SMALL CHANNELS, FILM AND WATER POCKETS INCREASE THE BASAL PRESSURE AND **CAUSE THE GLACIER SLIDING**

HYDRAULIC SYSTEM CAN CHANGE FOR THE GLACIER MOTION

EFFICIENT WATER DRAINAGE

LIMITED WATER DISCHARGE

CAVITY

R-CHANNELS

H-CHANNELS

FILM

CAVITIES

EFFICIENT DRAINAGE

INEFFICIENT DRAINAGE
CONCLUSIONS

DIC PROVIDES MAPS OF SURFACE KINEMATICS. THE DISPLACEMENT PATTERN INDICATE WHERE THE STRONGEST STRESSES ACT. THIS IS IN ACCORDANCE WITH THE FORMATION AND POSITION OF CREVASSES.

THEREFORE, THE ANALYSIS OF THE KINEMATIC MAPS CAN BE A FIRST EVALUATION TO IDENTIFY POSSIBLE UNSTABLE BODIES AND TO ESTIMATE THEIR VOLUME.

THE VELOCITY-VOLUME RELATIONSHIP CAN PROVIDE AN A-PRIORI ESTIMATE OF THE BREAK-OFF.

A STRONG VELOCITY INCREASE CAN BE A PRECURSOR OF A LARGE COLLAPSE

TIME-LAPSE IMAGERY CAN BE A VALUABLE TOOL FOR RISK ASSESSMENT

DIC PROVIDES RESULTS WITH DAILY TEMPORAL RESOLUTION AND CANNOT BE APPLIED DURING NIGHT AND BAD WEATHER

PRESENTLY, IT IS NOT POSSIBLE TO PREDICT THE INSTANT OF THE BREAK-OFF

DIC CAN NOT BE USED FOR EARLY WARNING ACTIVITIES
THANK YOU

BIBLIOGRAPHY


4. IKEN, A. (1977) MOVEMENT OF A LARGE ICE MASS BEFORE BREAKING OFF. JOURNAL OF GLACIOLOGY, 19(81), 595-605


NICCOLO.DEMATTEIS@IRPI.CNR.IT
HTTPS://WWW.RESEARCHGATE.NET/PROFILE/NICCOLO_DEMATTEIS
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